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Interactive comment on "The impact of the North American ice sheet on the evolution of the Eurasian ice sheet during the last glacial cycle" *by J. Liakka et al.*

Anonymous Referee #1

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General remarks

The objective of the authors is to model the impact of the Laurentide ice sheet on the evolution of the Eurasian ice sheet during several stages of the last glacial. Ideally, one would employ a fully coupled atmosphere-ocean-ice sheet model and make simulations over the full last glacial cycle to account for the memory of the climate system and to incorporate all feedbacks between the atmosphere, ocean and ice sheets. However, the existing comprehensive models are still rather expensive to use, implying that it is not yet feasible to perform such long experiments. One solution is to apply intermediate complexity models (e.g. Ganopolski et al. 2010). Liakka and colleagues have used

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an alternative approach, by running a chain of models sequentially, and by using the results of the previous step as input. The first step in this chain is the LGM simulation performed with the CCSM3 AOGCM by Brandefelt & Otto-Bliesner (2009). Secondly, these CCSM3 simulations were utilized to derive ocean heat transport (OHT) representations for the LGM and the preindustrial era that were used as a boundary condition in experiments performed with the CAM3 atmospheric GCM coupled to a mixed layer ocean model. In addition, different ice sheet configurations for MIS5b, MIS4, and LGM, based on reconstructions by Kleman et al. (2013), were also employed as boundary conditions in these CAM3 experiments. Finally, the atmospheric fields from the CAM3 experiments were applied as forcings for MIS5b, MIS4 and LGM simulations performed with the SICOPOLIS ice sheet model. The analyses presented in the paper are mostly based on the CAM3 experiments with preindustrial OHT, because the authors argue that the CAM3 experiments with LGM OHT produced a too cold climate in the North Atlantic area when compared to proxy-based temperature reconstructions.

The main result of the presented model experiments is that the Eurasian ice sheet migrates westward in MIS4 and LGM due to the impact of the growing Laurentide ice sheet on the atmospheric circulation. This result appears to be robust under different experimental setups (preindustrial and LGM OHT). The westward migration of the Eurasian ice sheet in MIS4 and LGM is consistent with reconstructions. However, in the MIS5b experiments, no westward migration of the Eurasian ice sheet is simulated, in conflict with reconstructions. The authors explain this mismatch by suggesting that under MIS5b boundary conditions, the ice sheet is not in equilibrium with the climate.

This paper deals with an important topic and the results presented are in principle of interest to the readers of Climate of the Past. However, as detailed below, I am not convinced that the experimental setup is fully appropriate to make this analysis. In my view, the main problem is that essentially all feedbacks between the ocean circulation and the ice sheet evolution are very poorly represented.

Main comments

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- The presented analysis for MIS5b, MIS4 and LGM is mainly based on experiments with a preindustrial OHT. The authors argue that the LGM OHT was inducing too cold conditions in the Atlantic Ocean, with a too extensive sea ice cover. Ideally, one would use specific OHT representations from experiments specifically designed for MIS5b, MIS4 and LGM. In my view, using the preindustrial OHT is really problematic, and is very likely to produce results that are not meaningful for the last glacial conditions, as it is very clear from palaeoceanographic evidence that the LGM North Atlantic Ocean was substantially colder than during the preindustrial era. I would argue that it makes much more sense to use the LGM OHT. There is evidence that in the North Atlantic Ocean the sea ice cover was extending to at least 45°N (e.g., Renssen & Vandenberghe, 2003). This would suggest that, at least for the LGM time slice, the results obtained with LGM OHT are more appropriate. I assume that the applied LGM OHT is based on the LGM2 state of Brandefelt & Otto-Bliesner (2009). I would argue that their LGM1 state would have been even more appropriate, as this state represents a stronger AMOC and less cold North Atlantic Ocean compared to the LGM2 state. In Otto-Bliesner et al. (2006), the simulated SSTs of LGM1 are compared to reconstructions, showing a good fit. I therefore strongly suggest repeating the analysis with CAM3 and SICOPOLIS with an OHT based on the LGM1 state.

- As noted, the LGM OHT used in the CAM3 experiments is derived from the CCSM3 simulations of the LGM climate. In my view, it is important to establish if the CCSM3 LGM climate is consistent with the LGM climate simulated by the CAM3 model. The atmospheric components in both models are basically the same (CAM3), but the two setups have different resolutions, very different ocean models and the simulations use different boundary conditions, e.g. the ice sheet configurations. If the climates are not consistent, I would argue that the CCSM3-derived LGM OHT should not be used in the CAM3 experiments.

- If understand correctly Löfverström et al. (2014), a modern annual-mean mixed layer depth is applied in the slab ocean model to specify the ocean's heat capacity in all

the glacial experiments used in the present study. Why was this done and what is the impact on the results? I propose to explain this in the methodology section.

- In my view Section 4 could be improved by discussing the obtained results relative to previous studies on the evaluation of ice sheets, for instance Ganopolski et al. 2010 and Beghin et al. 2014. Are the results consistent? If not, what is the reason?

Minor comments

- Figures 2, 3, 4: I wonder what the statistical significance is of the simulated anomalies. I suggest to perform a test (e.g. t-test for temperature) and to show only results that are statistically significant.

- Page 5205, line 6. "The stadials are referred to as the Marine Isotope Stages (MIS) 5d (106–115 kyrs BP), 5b (85–93 kyrs BP), 4 (60–74 kyrs BP) and 2 (12–24 kyrs BP". This sentence is confusing, as the meaning of stadials is not identical to that of Marine Isotope Stages. For instance, MIS4 includes 3 stadials according to the Greenland ice core record (e.g. Rasmussen et al. 2014) and MIS3 also includes stadials. So I suggest rephrasing.

- Section 2.1: I suggest including more information on the experimental setup, particularly the CAM3 experiments. For instance, for how many years have the CAM3 experiments been run? I suggest including a table with all boundary conditions and forcings. A flow diagram that explains the full experimental setup would also help.

- Page 5210, line 26: To estimate the fractions of solid and liquid precipitation, a limiting temperature is set. If the temperature is less than -10°C, all precipitation is solid, and if it is above 7°C, all precipitation is liquid. Between these temperatures, there are varying fractions solid and liquid precipitation. I was wondering what the rationale is for using -10°C and 7°C? On what are these values based?

- Page 5212, 2nd paragraph, starting line 11: Please clarify what experiments you compare here. Only the EA-only simulations, or also the fullGlacial runs?

- Figure 6: Is the longitude for the Eurasian ice sheet mass centre for the EAonly experiment on MIS4 consistent with Figure 5c? Visual inspection of the latter figure suggests that the centre of mass in the Barents Sea at ∼30°E, while Figure 6 suggests ∼55°E. How is the centre of mass defined?

- Page 5222, line 8: "between the MIS4 and LGM extents and the proxy suggests..." I propose to replace "proxy" by "proxies"

- Page 5223, line 17: should be "yields cooler summer temperatures"

- Page 5223, line 22: should be "an equivalent"

- Page 5224, line 13: should be "our results are"

Additional references Ganopolski, A., Calov, R., Claussen, M. (2010) Simulation of the last glacial cycle with a coupled climate ice-sheet model of intermediate complexity. Clim Past 6, 229-244. Otto-Bliesner, B. et al. (2006) Last Glacial Maximum and Holocene climate in CCSM3. J Climate 19, 2526-2544.

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